

CLARK ATLANTA UNIVERSITY

High Performance Polymers and Composites (HiPPAC) Center

NASA Cooperative Agreement NCC3-552

Final Report

Director:
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EXECUTIVE SUMMARY

NASA University Research Centers funding has allowed Clark Atlanta University (CAU) to establish a High Performance Polymers And Composites (HiPPAC) Research Center. Clark Atlanta University, through the HiPPAC Center has consolidated and expanded its polymer and composite research capabilities through the development of research efforts in: (1) synthesis and characterization of polymeric NLO, photorefractive, and piezoelectric materials; (2) characterization and engineering applications of induced strain smart materials; (3) processable polyimides and additives to enhance polyimide processing for composite applications; (4) fabrication and mechanical characterization of polymer based composites.

The increased demand for high performance materials for aerospace and military transportation, payload and mission requirements is accelerating the need to extend the capabilities of current materials systems. High performance polymers, composites and smart material systems are capable of providing novel ways of satisfying these demands.

High performance polymers and composites are high priority research areas of this nation's high technology global competitors, e.g. Europe and the Pacific Rim countries. To maintain a competitive edge, the United States needs to develop integrated centers to bring to bear a larger and diverse set of university-based investigators who collaborate as an integrated unit with their counterparts in industry. Thus, the goal of the HiPPAC Center is not only to study high performance polymers and composites, but also to effect technology transfer of these materials from the laboratory to the marketplace.

Since the performance characteristics of materials are determined by synthesis, structure, properties and processing, the strategy of the HiPPAC Center is to carry out basic and applied research directed to the understanding of the structures and interfacial properties of the components of advanced materials systems. Combining this with a better understanding of the effect of processing on the micro- and macro-structure of these materials facilitates the optimization of properties for specific high performance applications.

A major focus of the HiPPAC Center is the synthesis, characterization, properties and processing of polyimides. These are advanced materials that have good high temperature stability, excellent dimensional stability, and excellent mechanical, electrical, and chemical resistance properties. They can be molded (jet engine parts, glass fiber-reinforced blocks, printed wiring boards, etc.), produced as films (electric motors, flat flexible cable and magnetic wire insulation for aircraft and missiles, etc.), or applied as coatings (semiconductor devices and electrical components). Polyimides which exhibit NLO behavior have applications in fast electro-optic switches and modulators for optical communication, laser frequency conversion and optical switches for ultrafast computation. Polyimide based photorefractive materials are the principal candidates for applications including high-density optical data storage and image processing. Piezoelectric polymers have applications such as active suppression of vibration, health monitoring of composite structures and joints in trussed systems.

Polymer Matrix Composites (PMC) and Hybrid Metal Composite Laminates (HMCL's) have attracted considerable interest for use in aircraft engines and airframes because of their light weight and high strength. The use of PMC's and HMCL's to replace metals results in significant weight savings leading to improved performance and fuel economy, and increased aircraft range of passenger or payload capacity.

A major objective of the HiPPAC Center is the vigorous recruitment, training, and graduation of socially- and economically-disadvantaged students who are U.S. citizens and who have historically been underrepresented in the NASA related fields of chemistry, physics and engineering. An additional goal of the HiPPAC center is to increase the number of socially- and economically-disadvantaged students holding advanced degrees in materials chemistry, physics, and engineering thus developing a base of professionals to meet our nation's future manpower needs in materials science and related fields.

We believe that we have brought together a highly qualified team of investigators with the proper skills to address important problems in the synthesis, characterization and processing of high performance polymers and composites. Because of the strong capabilities of the Center team in polymers and composites research and the attendant manpower training, especially of minority students, the HiPPAC Center is unique among the HBCUs and indeed in the nation.

Clark Atlanta University is strongly committed to the continued development of the High Performance Polymers and Composites Center. This is evidenced by the fact that a materials science research and education program with emphasis on polymers was included in the strategic plans of the CAU Research Center for Science and Technology. Since the inception of the HiPPAC Center in 1992, the University has added new tenure track faculty in chemistry, physics and engineering many of which are working in the areas of high performance polymers or composites. The university begun an undergraduate engineering program which has now graduated two classes.

Strategic Focus

Faculty of the CAU NASA High Performance Polymers and Ceramics (HiPPAC) Center have worked closely with the NASA Technical Review Committee (TRC) over the past eight years to ensure that the focus and scope of our work meet NASA goals and objectives. To this end the HiPPAC Center has, with NASA's support, developed the infrastructure and focus necessary to carry out cutting edge research in high performance polymers and composites to address problems important to the aeronautics and space transportation, and to meet the nation's needs. The HiPPAC Center has focused its research programs in high performance polymers and composites. The primary focus of the Center is fundamental and applied research and the attendant human resources development in chemistry, materials science and engineering. The research and technology that will be developed as a result of this work will play a vital role in ensuring the safety, environmental compatibility, and productivity of the air transportation and space systems and have a part in enhancing the security and economic health of the nation. Research being carried out in the HiPPAC Center complements work that is being

carried out at the NASA Langley Research Center (LaRC) Composites and Polymers Branch and Mechanics of Materials Branch, and the NASA Glenn Research Center (GRC) Polymers Branch and Materials Division.

Research work:

A major focus of the HiPPAC Center is the synthesis, characterization, properties and processing of polyimides. These are advanced materials that have good high temperature stability, excellent dimensional stability, and excellent mechanical, electrical, and chemical resistance properties. They can be molded (Jet engine parts, glass fiber-reinforced blocks, printed wiring boards, etc.), produced as films (electric motors, flat flexible cable and magnetic wire insulation for aircraft and missiles, etc.), or applied as coatings (semiconductor devices and electrical components).

Another focus of the HiPPAC Center is preparation and characterization of nonlinear optical (NLO), photorefractive and piezoelectric polymers. Polyimides which exhibit NLO behavior have applications to fast electro-optic switches and modulators for optical communication, laser frequency conversion and optical switches for ultrafast computation. Polyimide-based photorefractive materials are the principal candidates for applications including high density optical data storage and image processing. These polymeric NLO and photorefractive materials have applications to developing "flight by fight" systems and to optical computing and information storage which will be the basis of information systems technology that will enable significant advances in the design, manufacture and testing of aircraft in "virtual wind tunnels". Piezoelectric polymers have applications such as active suppression of vibration, health monitoring of composite structures and joints in trussed systems.

A third research focus of the HiPPAC Center is smart material systems, an emerging technology area aiming toward the development of material systems and structures that can rearrange themselves to their optimum functional capabilities to adapt to external stimuli by using inherent or integral functional elements such as sensors, actuators, and controllers. For the past decade, engineering applications implementing smart material system concepts have demonstrated many prominent functional capabilities that the integrated sensors, actuators, and control system can achieve. The concept of smart material systems can be implemented to aerospace applications of NASA interests, such as health monitoring, active damage control, and active vibration control of aerospace structures. The key objectives of the smart materials research at HiPPAC are to conduct basic research in characterizing the coupled-field behavior of induced strain materials, such as piezoelectrics, and applied research in developing health monitoring techniques for engineering structures using induced strain actuators and sensors.

Another focus of the HiPPAC research program is the design, fabrication, processing, durability, testing and modeling for life time prediction, and aging of Polymer Matrix Composites (PMCs) and Hybrid Titanium Composite Laminates (HMCLs). The center has recently moved into the area of Resin Transfer Molding (RTM) to prepare PMCs. The success that the center has had working with Lockheed Martin and NASA on advanced composite processing methods clearly indicates that the Center is on the cutting

edge of composite processing technology. We are focusing on the fundamental materials issues at the microscale and interfaces, analytical modeling, thermomechanical fatigue testing and evaluation, and constitutive and damage modeling. The use of PMCs and HMCLs in place of metals results in significant weight savings leading to improved performance and fuel economy, and increased aircraft range of passenger or payload capacity.

The aerospace industry needs lightweight structural materials possessing superior strength/weight and/or modulus/weight characteristics. These materials will be utilized in future aerospace structures, including aircraft, missiles and spacecraft. The development of optimum lightweight structural materials requires a balance of properties and an efficient, low-cost processing methodology. Since future aircraft and space systems will remain in service for longer periods of time, the prediction of aging effects will be extremely important during the design and development of new materials. Advanced composites and hybrid titanium and polymeric matrix composite laminates have the potential of meeting this need.

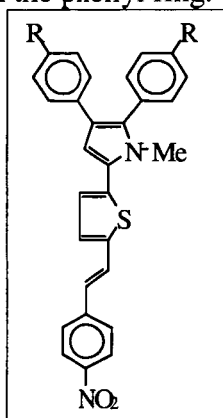
PROGRAM GOALS, OBJECTIVES AND RESULTS

Faculty of the CAU NASA HiPPAC Center have worked closely with the NASA Technical Review Committee (TRC) to ensure that the focus and scope of the center's work meets NASA goals and objectives. The HiPPAC Center has, with the NASA TRC support, developed the infrastructure and focus necessary to carry out cutting edge research in high performance polymers and composites to address problems important to the aeronautics and space transportation industries. The basic research and technology results of the HiPPAC Center should play a vital role in ensuring the safety, environmental compatibility, and productivity of the air transportation and space systems and in enhancing the security and economic health of our nation. The research and development of the HiPPAC Center complements work that is being carried out at the LaRC Composites and Polymers Branch and the Mechanics of Materials Branch, and the GRC Polymers Branch and Materials Division.

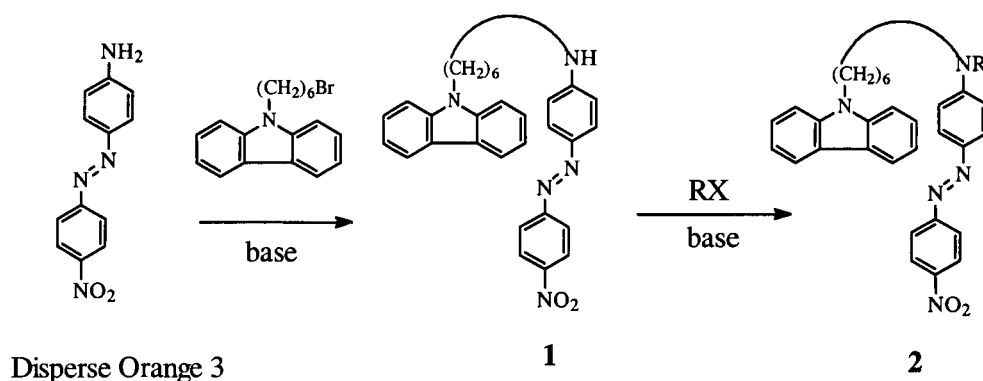
Synthesis and Characterization of Nonlinear Optical, Photorefractive, Photoluminescent and Electroluminescent Polymers (NLO/LE). One research and development focus of the HiPPAC Center was preparation and characterization of nonlinear optical (NLO), photorefractive, photoluminescent and electroluminescent polymers. Polyimides which exhibit NLO behavior have applications to fast electro-optic switches and modulators for optical communication, laser frequency conversion and optical switches for ultrafast computation. Polyimide-based photorefractive materials are the principal candidates for applications including high density optical data storage and image processing. These polymeric NLO and photorefractive materials have applications to developing "flight by fight" systems and to optical computing and information storage, which will be the basis of information systems technology that will enable significant advances in the design, manufacture and testing of aircraft in "virtual wind tunnels." Photoluminescent and electroluminescent polymers are key materials for the development and production of advanced display devices, such as flat panel displays that

have far higher readability than LCD display, are smaller, and have much lower power consumption than CRT displays.

NLO and photorefractive polymers. We have developed thermally stable imidazole and carbazole based organic and polymeric NLO materials that can be readily tailored for attachment to a polymeric backbone. We have prepared a new class of imidazole based NLO chromophores which exhibit high thermal stability (up to 340 °C). Electric field induced second-harmonic generation (EFISH) measurements have confirmed that these compounds exhibit nonlinear-optical behavior, expressed as $\mu\beta$, ranging from 270 to 690 $\times 10^{-48}$, varying with the R group on the phenyl ring.



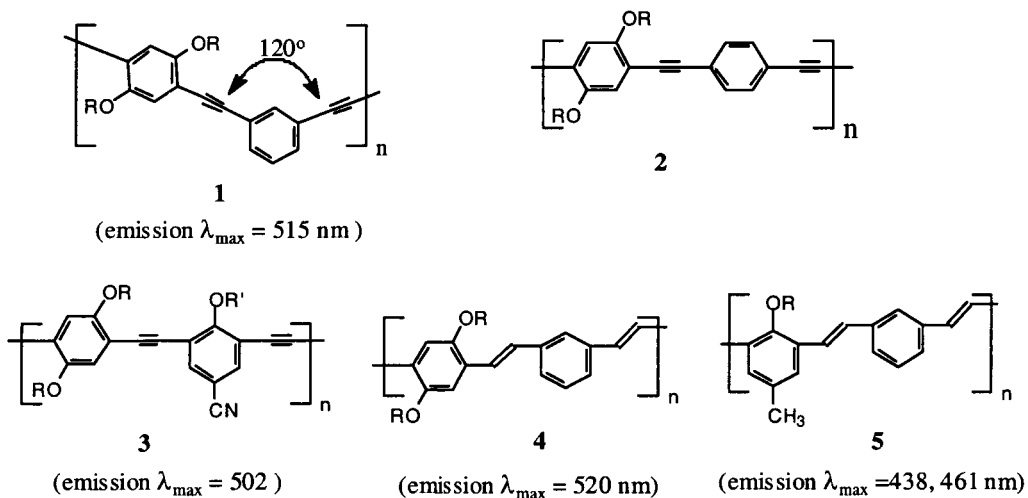
We have also developed a new class of bifunctional molecules **2** which incorporates the two key components that are required for photorefractive materials, an azo dye that functions as an NLO chromophore, and a carbazole unit that functions as a charge-transporting agent. The EFISH measurement indicates that the molecule **2** ($\mu\beta = 930 \times 10^{-48}$ esu) possesses much larger second-order nonlinearity than **1** ($\mu\beta = 570 \times 10^{-48}$ esu) due to the alkyl group R acting as an additional donor in **2**.



Preparation And Characterization Of Non-Linear Optical (NLO), Photorefractive, Photoluminescent (PL), and Electroluminescent (EL) Polymers: Polymers with extended π -conjugation have received increasing attention in the microelectronic industry due to their potential application as conductors, third-order NLO material, and as light-emitting diodes. Polymer based light-emitting diode displays have been shown to be much brighter than liquid-crystal displays when viewed from an angle. We have found

that poly(*m*-phenyleneethynylene)-*alt*-(*p*-phenyleneethynylene) **3**, exhibits very high photoluminescence and promising electroluminescence (EL) for LED applications. We have recently modified this polymer by introducing cyano groups into the polymer backbone to give polymer **4**, which exhibits significantly higher PL in the solid state than **3**. In collaboration with scientists at Ames Laboratory (USDOE) and the University of Massachusetts, **4** has been used as the active emission layer to fabricate LED devices with improved EL intensities in comparison with the corresponding devices from using polymer **3**.

Preparation And Characterization Of Photoluminescent (PL), Electroluminescent (EL) Photorefractive, and Non-Linear Optical (NLO) Polymers: Polymers with extended π -conjugation have received increasing attention in the microelectronic industry due to their potential application as conductors, third-order NLO material, and as light-emitting diodes. During the past few years, we have developed several new π -conjugated polymers with high luminescence. For example, poly[(2,5-dialkoxy-1,4-phenyleneethynylene)-*alt*-(1,3-phenyleneethynylene)] (**1**) exhibits improved photoluminescent (PL) efficiency in comparison with its isomer **2**, especially in the solid state. A *meta*-phenylene unit along the polymer chain introduces a bent angle, thus reducing the interchain interaction and improving the polymer morphology in the solid state. Direct comparison under identical conditions shows that the film **1** emits about five times as strong as that of **2**. Our recent results show that the presence of the *meta*-phenylene linkage significantly reduces the polymer aggregation, which lowers the quantum efficiency of the polymer films.



We have examined the electroluminescent properties of several of these polymers. While both polymers **1** and **4** give green electroluminescence (near 540 nm and 525 nm, respectively), the latter exhibits higher efficiency in both photoluminescence (PL) and electroluminescence (EL). By using the Wittig-Horner condensation to synthetically eliminate trace iodide impurities in the polymer, the LED device of **4** permits a balanced electron-hole injection, thus raising the device efficiency by a factor of 4-5 to 0.16%. Benefiting from the effective conjugation interruption at the *meta*-phenylene, poly(*m*-phenylene) derivative **5** gives a blue-emission in both PL and EL.

Our recent studies have shown that the PL efficiency of film 4 is as high as 80%. Its EL efficiency under the optimum condition, however, reaches only about 0.16%. The high PL but low EL efficiencies indicate a low population of excited states formed in the emissive polymer layer. Improving the charge-carrier injection into the polymer emissive layer should aid the formation of excited states, thereby raising the device EL efficiency.

Smart Materials. A second research and development focus of the HiPPAC Center was smart material systems. This is an emerging technology area in the development of material systems and structures that can rearrange themselves for optimum functional capabilities to adapt to external stimuli, by using inherent or integral functional elements such as sensors, actuators, and controllers. For the past decade, engineering applications implementing smart material system concepts have demonstrated many prominent functional capabilities of integrated sensors, actuators, and control systems. Smart material systems can be implemented in aerospace applications such as health monitoring, active damage control, and active vibration control of aerospace structures. The key objectives of the smart materials basic research program are in characterizing the coupled-field behavior of induced strain materials, such as piezoelectrics, and applied research in developing health monitoring techniques for engineering structures, using induced strain actuators and sensors.

Sensors to detect debonding in structural adhesive joints. A new actuator/sensor layout and structural excitation scheme have been developed to study the effectiveness of using piezoceramic actuators and sensors to detect debonding in structural adhesive joints, such as those used in aerospace applications. The new actuator/sensor layout consists of an aluminum beam lap joint with one pair of surface-bonded actuators on one side of the joint and one pair of sensors symmetrically surface-bonded on the other side of the joint. The finite element method has been used to analyze this new actuator/sensor configuration. Steady-state analysis has been performed on both "healthy", i.e., undamaged, joints and "unhealthy", i.e., damaged, joints. The actuators were excited in-phase with a sinusoidal potential, the induced electrical potentials on the surfaces of the sensors were then obtained and recorded. The sensor signal response of the damaged joint is significantly different in terms of both amplitude and phases relative to the undamaged joint. The applications of this work is key to the health monitoring of aging aircraft.

Development of Solid State Hybrid Linear/Rotary Actuators. One way to increase flight efficiency and improve system reliability of aircraft and launch vehicles, would be to remove the centralized hydraulic pumps, distributed pressure and return lines, valves, and accumulators and replace them with a compact, light-weight, all-electric actuation system.

In this project, a novel solid state actuation system is being developed. The actuation system uses active smart materials to generate hybrid linear/rotary "inchworm" type motion that delivers large stroke and high force/torque output and can be used to replace the existing hydraulic control system in air and space vehicles. The solid state hybrid linear/rotary stepper motor uses Lead Zirconium Titanate (PZT) piezoceramic materials

as the synchronized drivers to move a core rod in a manner similar to the crawling motion of an inchworm.

A prototype motor has been fabricated for concept demonstration. Both single and dual actuator configurations have been tested. It was determined that the induced actuation strains of a solid PZT actuator element are too small, less than 1 micron, to drive the motor core. Modifications of the original concept were made by replacing the engage/disengage control PZT element with a PZT stack actuator, which induces a maximum of 8 micron.

In preliminary tests, a 100 V static voltage was applied to the PZT stack to activate engagement force. It was observed that total engaged and disengaged states between the motor core and the actuator were completely distinguishable. In other words, the engagement force generated by the PZT stack appears to be sufficient to drive the motor core. A 100 V and $-1,500$ V sine wave control signals with 40 Hz frequency have been tested on the PZT stack and the block, respectively, with a 90° phase angle difference. Under this driving condition, an encouraging 1 mm/min motor core motion was observed.

The success of the project will produce an all-electric high-efficient actuator that can be used to replace the existing cumbersome hydraulic actuation systems found in all air and space vehicles. It is expected that with the solid state smart actuation system a substantial vehicle weight saving and maintenance cost reduction can be realized.

Health Monitoring Of Large Aerospace Structures Using High Sensitivity Electrical TDR Distributed Strain Sensor. Electrical time domain reflectometry (ETDR) sensing technique can be best described as "closed-loop radar," where the information is derived from the reflections of a voltage pulse sent through a transmission medium. The ETDR sensing technique is a well-developed method and has been widely used to locate and evaluate discontinuities in long coaxial power transmission cables. The ETDR technique provides a true distributed sensing capability which can not only sense the distributed loading condition of the structure but also can pin-point the location of disturbance, such as the locations of stress concentration and structural damages.

Proof-of-concept experiments have been conducted using photoelastic specimens with embedded commercial coaxial cables, i.e., RG85/U and RG174, to demonstrate the stress/strain sensing capability of ETDR sensors for structural health monitoring application. Although the test results showed that the ETDR sensor signals capture specimen deformation pattern both in bending and tension and indicate the location and type of crack damages of the photoelastic specimen; yet, the low signal-to-noise ratio of the sensor signal smears the details of the strain measurement that the ETDR signals can convey.

A high-sensitivity ETDR coaxial strain sensor prototype has been developed at Clark Atlanta University. It was shown in laboratory tests that the prototype ETDR sensor has a much higher sensitivity than their commercial coaxial cable counterparts. In this project, the potentials of the ETDR distributed strain sensing method for shape

measurement and health monitoring application of large flexible aerospace structures were investigated.

Proof-of-concept study has been conducted using a large flexible 1.5"x0.2"x72" wooden beam with a surface-bonded ETDR prototype sensor. It was demonstrated that the high sensitivity ETDR distributed strain sensor captures the deformation profiles of the flexible structure. Under first mode bending, the ETDR sensor was subjected to tensile load throughout the structure length, while under second mode bending, the sensor was subjected to compression in the section near the fixed end and subjected to tension in the rest of the structure. These bending profiles were correctly represented by the ETDR signal response of the sensor.

The preliminary results of the concept demonstration test successfully show promising potentials of the ETDR distributed strain sensor for shape measurement and health monitoring applications of large flexible structures. Currently, on-going efforts are undertaken to address the issues such as miniaturization of the sensor, improvement of ETDR signal sensitivity, and signal noise reduction.

The novel ETDR distributed strain sensor has a great potential for the use health monitoring of aircraft wings, satellite lattice and boom structures, as well as space station structures.

Fabrication and Mechanical Characterization of Polymer Matrix Composites (FCPMC). Another focus of the HiPPAC research program was the design, fabrication, processing, durability, testing and modeling for life time prediction, and aging of Polymer Matrix Composites (PMCs) and Hybrid Titanium Composite Laminates (HTCLs). The Center recently moved into the area of Resin Transfer Molding (RTM) to prepare PMCs. The success of the Center in working with Lockheed Martin and NASA on advanced composite processing methods clearly indicates that the Center is on the cutting edge of composite processing technology. HiPPAC researchers are focusing on fundamental materials issues at the microscale and interfaces, analytical modeling, thermomechanical fatigue testing and evaluation, and constitutive and damage modeling. The use of PMCs and HTCLs in place of metals would result in significant weight savings leading to improved performance and fuel economy, and increased aircraft range of passenger or payload capacity.

The aerospace industry needs lightweight structural materials possessing superior strength to weight or modulus to weight characteristics. These materials will be utilized in future aerospace structures, including aircraft, missiles and spacecraft. The development of optimum lightweight structural materials requires a balance of properties and an efficient, low-cost processing methodology. Since future aircraft and space systems will remain in service for longer periods of time, the prediction of aging effects will be extremely important during the design and development of new materials. Advanced composites and hybrid titanium and polymeric matrix composite laminates have the potential of meeting this need.

HiPPAC research in the fabrication and mechanical characterization of polymers and composites involves durability and characterization of polymers and composites and advanced processing methods for high performance composites for NASA and the aerospace community in areas such the High Speed Research (HSR), Advanced Subsonic Technology (AST), Reusable Launch Vehicle (RLV), and High Temperature Engine Materials (HiTEMP) programs. The main objectives of Group IV are to investigate novel, cost effective techniques to improve composite manufacturing and to demonstrate that advanced polymers and polymeric composites will be useful as primary structures in aerospace applications in terms of durability, reliability, safety, life cycle performance and costs.

Research on the durability of advanced materials has resulted in the development of experimentally-based methodologies for lifetime assessment of polymeric composites under tension-tension and tension-compression fatigue. Test programs were carried out to predict the stress vs. number of cycles diagram while monitoring the stiffness degradation of the laminates under ambient and elevated temperatures. Analytical studies were also performed to present a methodology for the prediction of laminate strength and load-deformation behavior based on the strengths and stiffnesses of its laminae. Predictions of the long-term behavior of polymeric composites were accomplished by developing accelerated test methods, theoretical models, and computational techniques involving time, environmental exposure and load as the major factors in durability modeling. Research was also aimed at investigating the long term effects of time and temperature on polymer bonded joints through the understanding of the physics of degradation mechanisms. Interfacial fracture mechanics, in conjunction with microstructural data, enabled the development of constitutive models to simulate damage evolution in adhesive bonds. Traditional mechanics, as well as an interdisciplinary micromechanics/material science approach was used to obtain a fundamental understanding of the effects of load, environment, and time (aging) on the mechanical behavior (durability) and time dependent response of high-performance ultra-lightweight polyimide based foams. Finally, novel processing techniques were developed to successfully resin transfer mold NASA's LaRCTM-PETI-5 composites.

Testing of NASA developed materials (composites and foams) has helped develop the necessary mechanical property databases that will enable their use in aeronautics applications such as the Reusable Launch Vehicles (RLV) cryotank insulation. This effort has supported A efforts at both LaRC and GRC under the RLV Focused Technology, Bantam, and High Operating Temperature Propulsion Components programs.

PROGRAM OUTCOMES AND EFFECTS

Educational Attainments (Institution, Students, Faculty). The HiPPAC Center and the EPA and Army funded Center for Environmental Policy, Education, and Research (CEPER) were key to the initiation of the Department of Engineering at CAU. The CAU Engineering Department graduated its first students in 1999. URC funds were used to recruit and hire approximately one half of the engineering faculty. Additional three polymer chemists were added to the Chemistry Department as part of the URC program.

This initiation of the engineering program and the strengthening of the chemistry program have had, and will continue to have, a major impact on CAU's science and engineering programs. All of the faculty hired as part of the URC program have earned tenure, which represents a very long-term commitment by the University.

Equipment/Infrastructure/Facilities Enhancements. The faculty of the HiPPAC has utilized a combination of URC funds and leveraged funds to develop and enhance the CAU's infrastructure to carry out materials science research and development. The enhanced infrastructure is organized in the following fabrication, characterization and processing laboratories: Mechanical Testing, Rheology and Processing; Surface Analysis; Vibrational, UVVis, and Fluorescence Spectroscopy; Thermal Analysis, Nuclear Magnetic Resonance Spectroscopy; X-Ray; and Molecular Weight and Particle Characterization.

Research Productivity. Since the URC's inception, HiPPAC Center researchers have been very productive in the normal academic mode publishing over 145 papers, making over 150 presentations and training students. Perhaps more importantly to NASA, they have been productive members of important University-Industry-NASA research and development teams including: High Speed Research (HSR), Resin Transfer Molding (RTM) of polyimides, Hybrid Titanium Composite Laminates (HTCLs), Blended-Wing-Body Structural Technology Study, and Reusable Launch Vehicle (RLV).

PROGRAM IMPACT

The HiPPAC Center and the EPA and the Army funded Center for Environmental Policy, Education, and Research (CEPER) were key to the initiation of the Department of Engineering at CAU. The CAU Engineering Department graduated its first students in 1999. URC funds were used to recruit and hire approximately one half of the engineering faculty. Additional three polymer chemists were added to the Chemistry Department. This initiation of the engineering program and the strengthening of the chemistry program has, and should continue to have a major impact on the basic and applied research, education and technology programs at CAU. All of the faculty hired as part of the URC program have earned tenure, which represents a very long-term commitment by the University.

The HiPPAC Center was key to developing the chemical, civil, and mechanical engineering sub-disciplines of the CAU Engineering Department. The HiPPAC Center and its researchers have been instrumental in developing the infrastructure at CAU to carry out cutting edge research in polymers and composites, as well as offering students high quality educational and research opportunities in these areas. Also, because CAU is part of the AUC, with cross registration among AUC institutions, students at Morehouse, Morris Brown and Spelman colleges have also benefited from the increased depth of the CAU faculty, particularly, in engineering.

The development of a solid core of researchers and infrastructure to carry out research in the materials science and engineering areas at CAU has resulted in CAU being able to compete successfully for federal and industry research funds. The core facilities of

HiPPAC should assist CAU in its efforts to incubate start-up businesses in high tech materials science and engineering areas.

RELEVANCE TO NASA

The increased demand for high performance materials for aerospace and military transportation and mission is accelerating the need to extend the capabilities of current materials systems. High performance polymers and composites are capable of providing innovative ways of satisfying these demands. Over the past decade, the CAU NASA HiPPAC Center has worked closely with its NASA Technical Review Committee to ensure that the focus and scope of the Center meet NASA goals and objectives.

The Center's research and technology program make important contributions to ensuring the safety, environmental compatibility, and productivity of air transportation and space systems. Our research efforts complement the R&D objectives of the NASA Langley Research Center Composites and Polymers Branch and Mechanics of Materials Branch, and the NASA Glenn Research Center Polymers Branch and Materials

The future holds great promise for the development of strong, adhesively bonded, lightweight polymeric composite and nanostructured composite materials. Major applications are growing rapidly in the military, automotive, construction, aerospace and modern consumer markets. For NASA, in particular, the need for high strength, low weight advanced materials and structures has never been greater. There is an equally strong interest in the research areas of the HiPPAC Center in other federal agencies. High performance polymers and composites are high priority research areas of this nation's high technology global competitors. To maintain a competitive edge, the United States needs integrated research and technology centers that collaborate with their counterparts in industry. Thus, the goal of the HiPPAC Center is not only to study high performance polymers and composites, but also to effect technology transfer of these materials from the laboratory to the marketplace. Also, a major objective of the HiPPAC Center has been to increase the number of minority students earning advanced degrees in materials chemistry and physics, and engineering, thus producing professionals to meet our nation's technical manpower needs.

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BENEFITS TO SOCIETY

The future holds great promise for the development of strong, adhesively bonded, lightweight polymeric composite and nanostructured composite materials. Major

applications are growing rapidly in the military, automotive, construction, aerospace and modern consumer markets. Thus we expect continued, vigorous, basic and applied research opportunities in the areas of emphasis of the HiPPAC Center. There is an equally strong interest in the research areas of the HiPPAC Center in other federal agencies. High performance polymers and composites are high priority research areas of this nation's high technology global competitors. To maintain a competitive edge, the United States needs integrated research and technology centers that collaborate with their counterparts in industry. Thus, the goal of the HiPPAC Center is not only to study high performance polymers and composites, but also to affect technology transfer of these materials from the laboratory to the marketplace. Also, a major objective of the HiPPAC Center has been to increase the number of minority students earning advanced degrees in materials chemistry and physics, and engineering, thus producing professionals to meet our nation's technical manpower needs.

SUMMARY

The HiPPAC Center is a success story for both CAU and NASA. CAU has developed a highly qualified team of investigators with the proper skills to address important problems in the synthesis, characterization and processing of high performance polymers and composites. Because of the strong capabilities of the Center team in polymers and composites research and the attendant human resource development, especially of minority students, the HiPPAC Center is a unique resource among the HBCUs/MIs and indeed for the nation.

An excellent relationship has been developed between HiPPAC researchers and their counterparts at NASA GRC and LaRC. HiPPAC researchers have become integral contributors to important NASA programs, and the programs of key NASA contractors. An infrastructure has been established at CAU that should allow continued contributions to NASA and NASA contractor programs, and allows students to participate in and learn from high quality research programs.

A degree program has been established in engineering and the chemistry program has been strengthened, for the continued production of minority scientists and engineers to meet the human resource needs of NASA and NASA contractors in the future, and contribute to the diversity of the work force.